Evaluating the Impact of Urbanisation on Climate Change: A Case of Kochi City, Kerala State, India

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1 ABSTRACT

Urbanization significantly impacts climate by intensifying the urban heat island (UHI) effect, leading to increased heat-related risks from climate change. Changes in land use and land cover (LULC) during urbanization processes exacerbate heat stress in growing cities. The urban surface composition, structure, and emissions from various activities contribute to local climate changes that can be more pronounced than global climate predictions. With over half of the world's population residing in cities, which are often densely populated, the current urban population of 55% is projected to reach 68% by 2050. Cities typically have temperatures that are 2-3 °C warmer than their surroundings, with nighttime and wintertime variations being the biggest. Urban climate impacts like these make inhabitants more susceptible to upcoming environmental shifts, which makes cities ideal locations for climate adaptation and mitigation. The urban heat island effect, which occurs when cities are much warmer than surrounding rural regions, can amplify the effects of heat waves and increase urban energy demand for cooling. Keeping the aforesaid knowledge in mind, Kochi, a coastal city in Kerala State has been chosen as the study region for further detailed investigation. The study aims to evaluate the urban growth in the city over two decades from 2001 to 2021 and has an impact on the effect of urban heat islands through spatiotemporal analysis. The thermal load and dynamic potential layers are evaluated and integrated to generate a Climate Analysis Map to explore the hotspots of the study region. Based on the findings, the study concludes with plausible guidelines and strategies to minimize the impact UHI effect and to promote a sustainable built environment.

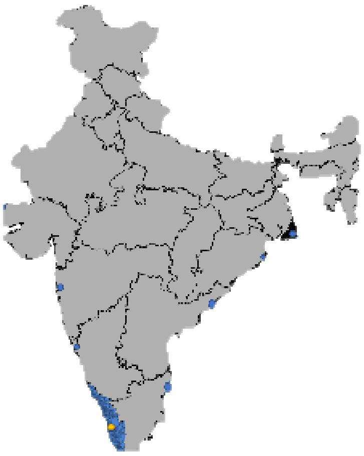
Keywords: climate change, complexity, urban heat island, land surface temperature, urbanisation

2 INTRODUCTION

Over half the world lives in cities and 70% of the population will live in cities by 2050. Over 60% of the land expected to become urban by 2030 is undeveloped. Asia's urbanisation rate will reach 50% by 2020. Only New York and Tokyo were megacities in 1970 but now Asia has 13 megacities, Latin America four and in 2025, 11.6% of urban dwellers will be in megacities, up from 9.9% in 2011. More than half of urban residents will live in small cities with less than 500,000 population. Africa and Asia will urbanize rapidly in the coming decades with Africa's urban population becoming three times and Asia's will 1.7 times in the next four decades. Cities emit up to 70% of greenhouse gases. Urban economic activity accounts for 55% of GNP in low-income nations, 73% in middle-income countries, and 85% in high-income ones. Urban heat islands (UHIs) are a significant concern in rapidly urbanizing areas like Kochi city in Kerala, India. The UHI effect, where urban areas experience higher temperatures than their rural surroundings, is exacerbated by factors such as population density, land management practices, and impervious surfaces (Elsayed (2012) Singh & Grover, 2014). Studies have shown that UHIs can lead to adverse effects such as increased thermal stress on citizens, elevated levels of air pollutants, and compromised human health and comfort (Graça et al., 2021; Liu et al., 2021). The phenomenon of UHIs is particularly important in cities and can create a vicious cycle where energy-intensive cooling methods contribute to further temperature increases (Dorghamy, 2022). Remote sensing technologies, such as Landsat data analysis, have been utilized to study UHIs and assess their impact on urban areas (Abraham et al., 2023; Ehsan et al., 2017). These technologies provide valuable insights into the spatial correlations between land use, surface temperature, and vegetation indices, aiding in understanding the dynamics of UHIs (Ehsan et al., 2017). Additionally, studies have highlighted the role of green spaces in mitigating UHIs by reducing solar radiation input and lowering temperatures through shade and transpiration (Radhakrishnan & Geetha, 2021; Qu et al., 2023).

3 STUDY REGION

Kochi, located in Ernakulam district of Kerala in India, is occasionally used to refer to a group of islands and towns that includes Ernakulam, Mattancheri, Fort Cochin, Willingdon Island, Vypin Island, and Gundu Island. Thrikkakara, Eloor, Kalamassery, and Trippunithura are part of the urban agglomeration. Kochi is a rapidly growing metropolitan centre on India's southwest coast, between 090 45' N and 100 20' N latitude and 760 10' E and 760 35' E longitude, with a shoreline spanning up to 47 kilometres. Estuaries are present which are nourished by perennial rivers that weave their way across the metropolis. Most of Kochi is below sea level. The climate in Kochi is tropical monsoon and due to its proximity to the equator and seaside position, it has low seasonal temperature change and moderate to high amounts of humidity. Temperatures in the air range from 20 to 35 °C (68 to 95 degrees Fahrenheit). Kochi Corporation covers an area of roughly 94.88 square kilometres. In terms of geographical size, Kochi Corporation is one of the smaller municipal corporations in the country, but it is heavily inhabited and highly urbanized. The Corporation has 74 wards, and the city's population is expected to reach over 6.5 lakhs by 2021.



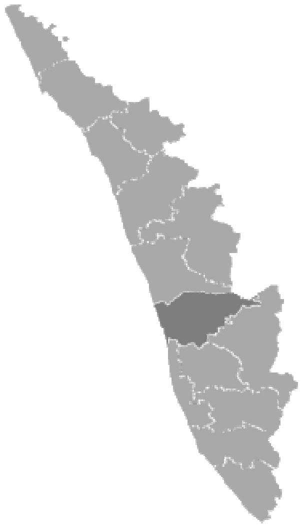


Figure 1 (left): Study Area India. Figure 2 (right): Study Area; Kerala. Source: authors.

Figure 3 (left): Study Area Ernakulam District. Figure 4 (right): Study Area Kochi Municipal Corporation. Source: authors.

4 LITERATURE REVIEW

Urbanization is the process through which people migrate from rural to urban regions, resulting in the emergence of larger, more complex cities. Cities are more complicated because they contain a wide range of activities, including economic, social, and environmental issues. The different factors that drive the growth of cities are referred to as urban dynamics. Demographics and economic, social, political, and environmental issues are examples of these factors that drive the city's growth. The influence of these processes is determined by the city's unique circumstances. Because of the numerous elements at play, such as population increase, land use, transportation, and infrastructure, urban dynamics are intricate. All of this may put a strain on the environment and the quality of life for individuals who live in cities. Urban planning is essential for dealing with the complexities of urban growth. It entails comprehending how various elements interact and forecasting how their activities will affect the city. This can aid in identifying areas of possible conflict or opportunity and in making decisions that will help the city flourish sustainably. Because urban expansion is difficult, cities require careful planning to ensure that everyone benefits.

Climate change is already affecting urban life, from overheating and floods to migration and economic turmoil. Urban leaders, governments, and multilateral organizations must work together to build climate resilience at scale, helping mature and emerging cities address rapid urbanisation, water resilience, congestion, air quality, green space per capita, land degradation, and urban sprawl. We assess and analyze climatic dangers and nature's influence in every urban system, from transit to buildings to social fabric, to help people prepare for these challenges. Kochi has a tropical monsoon climate, with heavy rainfall from June to September. Urban growth must include climate conditions to be sustainable and environmentally friendly. The city floods during the monsoon season due to its low-lying geography and high rainfall. Climate-responsive design should prioritize stormwater drainage systems, flood-resistant infrastructure, and land-use planning that avoids flood-prone areas. Green spaces in cities help reduce the urban heat island effect, which causes cities to be warmer than rural areas due to the high concentration of heat-absorbing materials like concrete and asphalt. Climate-responsive development must emphasize parks, gardens, and green roofs to cool the city. Energy-efficient buildings reduce the city's carbon footprint. Climate-responsible building design prioritizes energy-efficient structures that use renewable energy sources like solar and wind and should prioritize every vulnerability for conditions of living.

4.1 Vulnerability assessment

4.1.1 Urban Sprawl

Urbanisation extends metropolitan regions by creating homes and commercial centres farther from urban centres and connecting them with new main roadways. Suburban sprawl, or urban sprawl, is the extension of a city and its suburbs to low-density, auto-dependent development over rural terrain. As the city's population has risen, housing and infrastructure needs have skyrocketed, leading to chaotic and uncontrolled urban expansion. Traffic, infrastructural, and environmental issues resulted. Kochi's urbanisation has destroyed agricultural land, natural habitats, and increased pollution and affected water quality. Kochi's urban boom has caused rural migration, livelihood loss, and increased social and economic inequality.

4.1.2 Land Surface Temperature

Urbanisation changes urban land cover, usually through the reduction of vegetation, which affects surface climate. Due to heat capacity differences, materials with the same solar radiation have different temperatures. Urban climate depends on land surface temperature. Urbanisation can disrupt many natural processes, so studying its effects on Land Surface Temperature (LST) is crucial. Urbanisation and land usage have modified Kochi's land surface temperature (LST). Urbanisation and land usage have modified Kochi's land surface temperature (LST). When built up, vegetation-covered areas may have higher temperatures. Heat-related diseases including heat stroke and dehydration can increase with urban land surface temperature. Kochi, with a year-round tropical climate with high temperatures, is especially at risk.

4.1.3 Urban Climatic Map

Urban heat islands, air pollution, and floods can be identified using urban climate maps. Urban climate maps show urban heat islands as hotter areas of the metropolis. These areas often have few trees, plenty of concrete and asphalt, and a high building density. Increased green space, green roofs, and surface reflectivity can reduce urban heat islands. Urban climate maps can also show air pollution levels. Industrial activity, traffic, and green places may affect air pollution.

4.1.4 Urban Heat Island

Cities are usually warmer than rural areas. The city's size and shape affect the urban heat island's severity. Changes in ground cover, buildings' bulk and canyon-like shape, and vegetation decline cause heat absorption. Heating and other energy uses raise city temperatures, especially at high latitudes in winter. At lower latitudes, air conditioning raises outside temperatures and cools indoors. Due to reduced evaporation cooling from vegetation and forced drainage of rainwater, the urban water balance shifted creating the UHI.

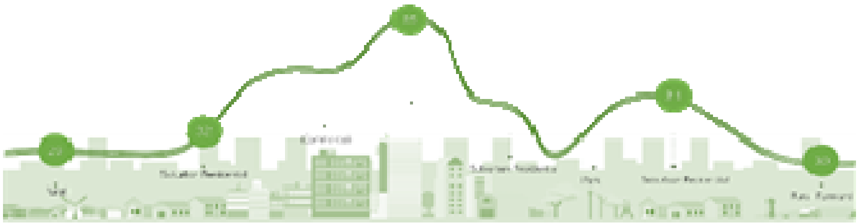


Figure 5: Generalized cross-section of a typical urban heat island. Source: authors.

5 METHODS AND DATA ANALYSIS

The research methodology is aimed at studying urban climate maps and urban heat islands and their mitigation. The various factors affecting urban heat island measurement were identified through various analyses. Analysis of the obtained data was done by using the software Arc Map 10.8. Initial studies have been done on the urban sprawl in the study area. From the built-up, the next study was done on the land surface temperatures of the study area from the data from satellite imagery.

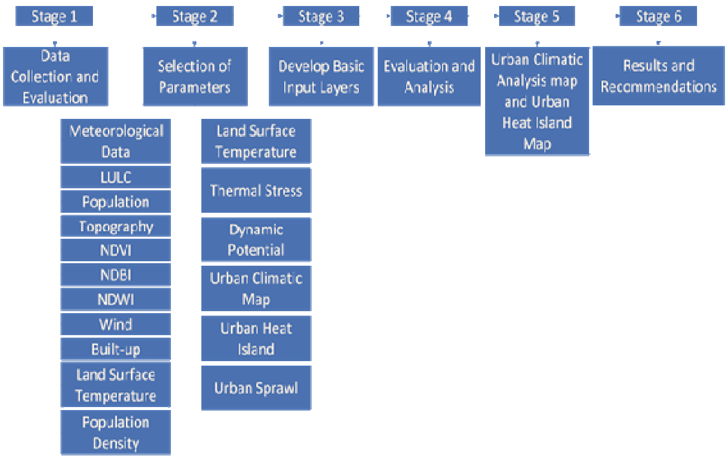


Figure 6: Research methodology. Source: authors.

6 RESULTS AND DISCUSSIONS

6.1 Urban Sprawl

Urban sprawl was studied in 2001, 2011, and 2021. Figure 5 shows that the built-up area has raised considerably in the last two decades. Due to emerging enterprises and commercial facilities, several vacant lands have been built up. Tree cover decreases with urbanization.

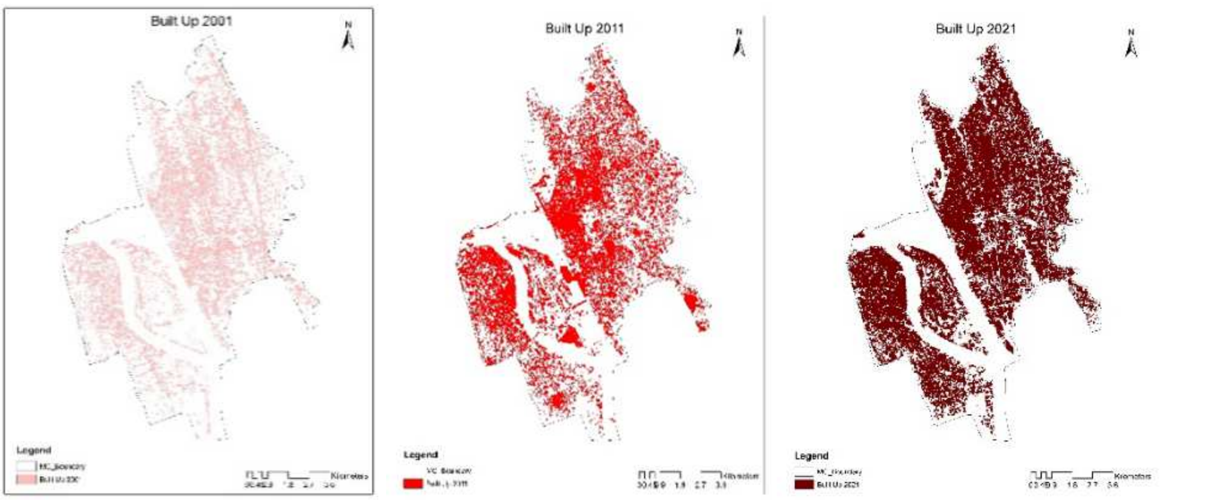


Figure 7 (left and middle): Built-up 200-2011. Source: authors. Figure 8 (right): Built-up 2021. Source: authors.

6.2 Land surface temperature

The radiative skin temperature of the land derived from solar radiation is known as land surface temperature (LST). LST measures the amount of thermal radiance emitted by the land surface where incoming solar energy interacts with and heats the ground or the canopy surface in vegetated areas. The land surface temperature can be significantly influenced by urbanisation. As cities and towns grow, natural landscapes are often replaced with buildings, roads, and other impervious surfaces that absorb and store heat differently than vegetation and soil. This can result in what is known as the urban heat island effect, in which cities have higher temperatures than surrounding rural areas. Kochi's development has had a considerable effect on land surface temperature. According to satellite imagery analysis, the LST in Kochi's urban regions was around 35°C, with a maximum of 36°C, while it was around 31°C in rural areas.

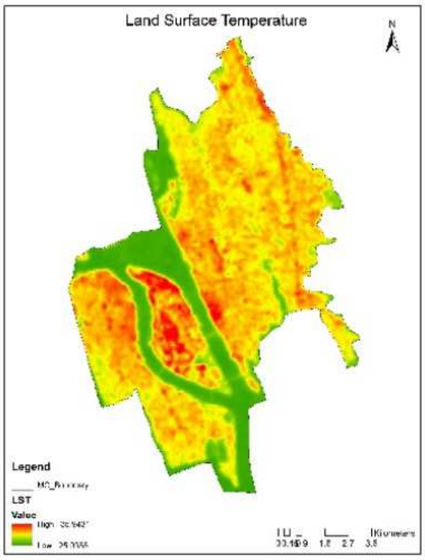


Figure 9. Land Surface Temperature (Source: authors.)

6.3 Urban climate map analysis

Thermal load and dynamic potential maps were used to combine the investigation of the urban climate. To determine the output of the thermal load and dynamic potential, several factors were examined. The urban climatic map shows us which places are sensitive and where climate intervention is needed, indicating high thermal load and low dynamic potentials.

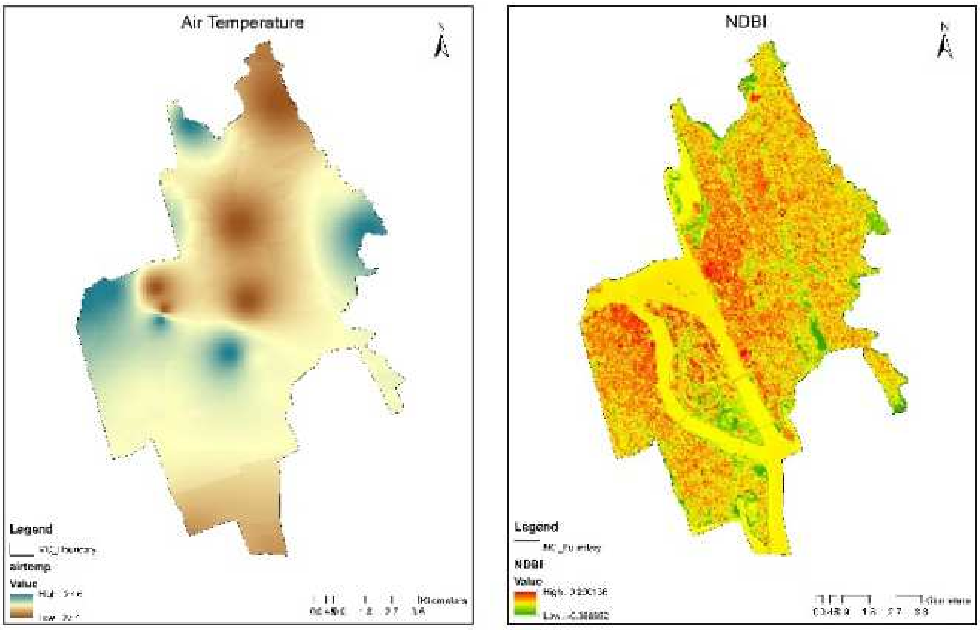


Figure 10: Air Temperature and NDBI

6.4 Thermal Load Map and Dynamic Potential

Thermal load in the context of urban climate refers to the quantity of heat energy created or absorbed by buildings, automobiles, and other sources in the urban environment. Because of the concentration of thermal load, this can contribute to the urban heat island effect, in which metropolitan regions suffer greater temperatures than surrounding rural areas.

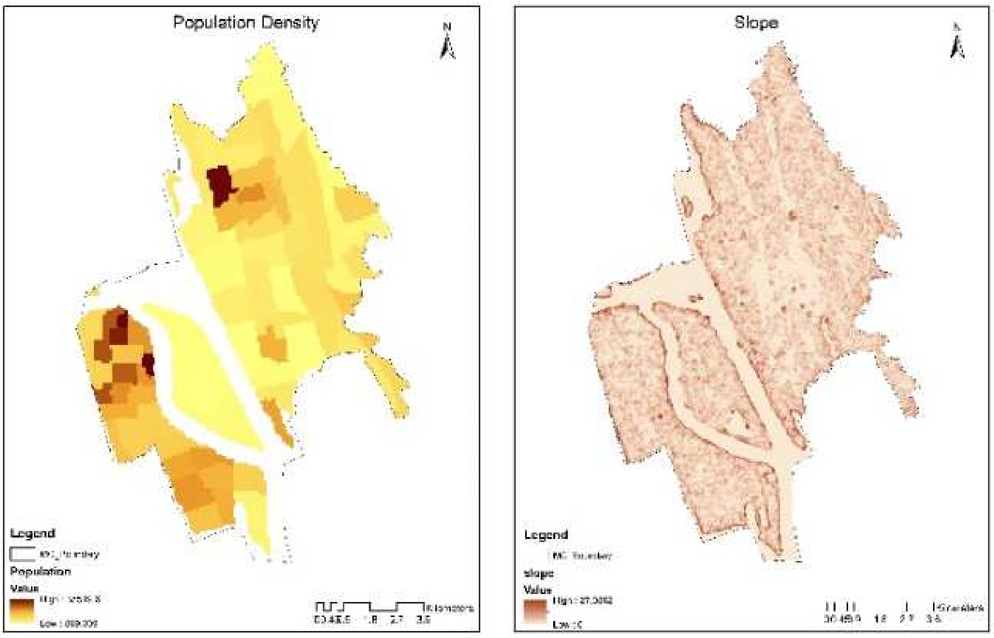
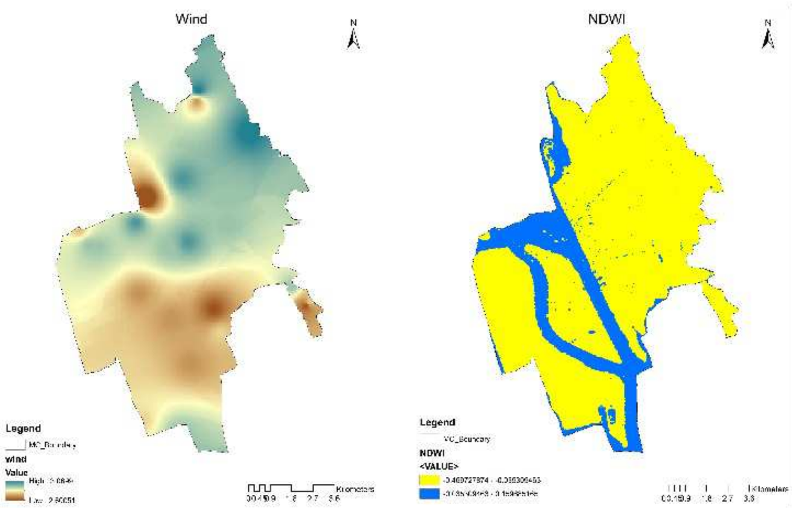


Figure 11: Population Density and Slope. Source: authors.

The capacity of the urban environment to adjust and react to changing circumstances, such as variations in temperature, precipitation, and other meteorological events, is referred to as dynamic potential in the context of urban climate. This can involve using green infrastructure, like trees and green roofs, to offer shading and cooling, using reflecting materials to lessen heat absorption and creating smart buildings that can vary their thermal load based on outside circumstances. The thermal Load and dynamic potential are integrated based on the 9 input factors indicated to produce the synthetic urban climatic map. The characteristics that have a negative correlation with temperature and may be used to better reduce UHI are merged to create a dynamic potential map. The input Layers related to the dynamic potential map is NDVI, NDWM, and Prevailing wind velocity, and the rest to construct a thermal Load map.



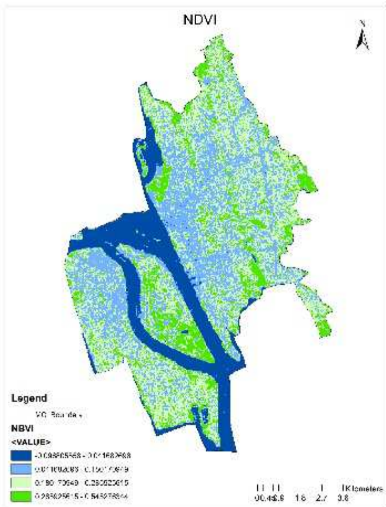


Figure 12 (left and middle): Prevailing Wind and NDWI of the Study Region. Source: authors. Figure 13 (right): NDVI of the Study Region. Source: authors.

6.4.1 Thermal Load Map and Dynamic Potential

The Urban Climatic map has been synergized from the dynamic potential and thermal load values. The map shows the sensitive areas which need planning intervention. The low value of sensitivity areas is those which are less populated. Urban climatic maps can offer important details on the layout of infrastructure, public areas, and buildings. The urban climatic map makes it clear that some areas of Fort Kochi, Vytilla, and some of the eastern sections of the study zone require intervention, such as parks and green spaces, the positioning of buildings to decrease heat gain, and the orientation of streets and buildings to optimize ventilation.

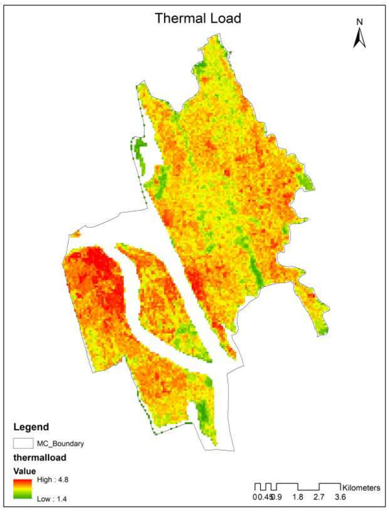
The climate map created is utilized to analyze the urban heat island of the Kochi city region. Parameter evaluation is by assigning scores to them with temperature. Because UHI is defined in terms of temperature, the study's parameters have units and all of them are brought on a common unit.

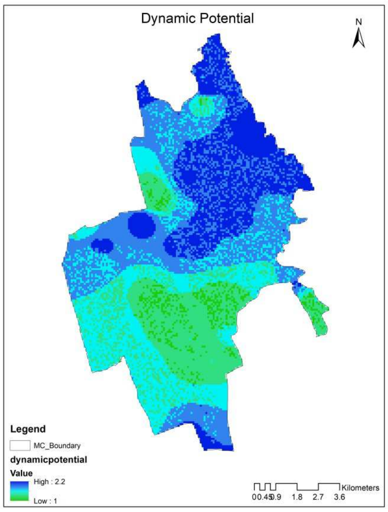
Parameter	Scoring Range	Very low temperature	Low temperature	Moderate temperature	High temperature	Very high temperature
	Score	1	2	3	4	5
LST	Parameter Range	very high comfort	high comfort	moderate comfort	low comfort	very low comfort
	Value	25-27	27-28	28-29	29-31	31-36
NDBI	Parameter Range	very low NDBI	low NDBI	moderate NDBI	high NDBI	very high NDBI
	Value	<-0.23	-0.22--0.15	-0.14--0.078	-0.077--0.0046	-0.0045-0.29
Population Density	Parameter Range	very low population density	low population density	moderate population density	high population density	very high population density
	Value	180-3200	3300-6400	6500-11000	12000-16000	17000-36000
Air Temperature	Parameter Range	very high comfort	high comfort	moderate comfort	low comfort	very low comfort
	Value	27.3-27.364	27.364-27.431	27.431-27.478	27.478-27.529	27.529-27.6
Topography	Parameter Range	very high topography	high topography	moderate topography	low topography	very low topography
	Value	0-0.86	.86-2.4	2.4-4.46	4.46-7.46	7.46-27.09

Table 1 Factors affecting thermal load and their impact on the urban environment.

Parameter	Scoring Range	Very low temperature	Low temperature	Moderate temperature	High temperature	Very high temperature
	Score	1	2	3	4	5
NDVI	Parameter Range	very high NDVI	high NDVI	moderate NDVI	low NDVI	very low NDVI
	Value	0-0.86	0.86-2.4	2.4-4.46	4.46-7.46	7.46-27.09
NDWI	Parameter Range	very high NDWI	high NDWI	moderate NDWI	low NDWI	very low NDWI
	Value	-0.47--0.264	-0.264--0.18	-0.18--0.076	-0.076-0.054	0.054-0.179
Prevailing wind	Parameter Range	fresh breeze	moderate breeze	gentle breeze	light breeze	light air
	Value	2.6-2.82	2.82-2.89	2.89-2.96	2.96-3.02	3.02-3.12

Table 2 Factors affecting dynamic potential their impact on the urban environment.





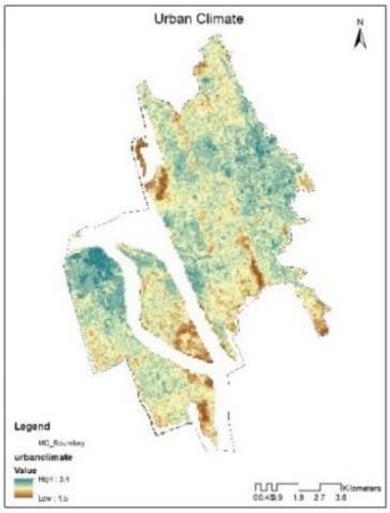


Figure 14 (left): Thermal Load. Figure 15 (middle): Dynamic potential. Figure 16 (right): Urban climatic map. Source: authors.

6.4.2 Urban Heat Island

Urban Heat Island has been generated by utilizing the land surface temperature. According to analysis, Kochi's UHI impact is strong, with temperature disparities between high- and low-built-up regions of up to 4-5°C ranging from 33 to 26 degrees in the city limits. The high population density, urbanization, and development are the primary causes of the temperature increase in Kochi. A rise in the number of structures, paved areas, and automobiles as a result of the city's recent fast expansion has increased the UHI impact. On the environment and people's health, the UHI effect in Kochi has several effects. It might result in higher cooling and air conditioning energy usage, which would raise greenhouse gas emissions and air pollution. The maximum temperature zone is on Willington Island which is a cantonment area.

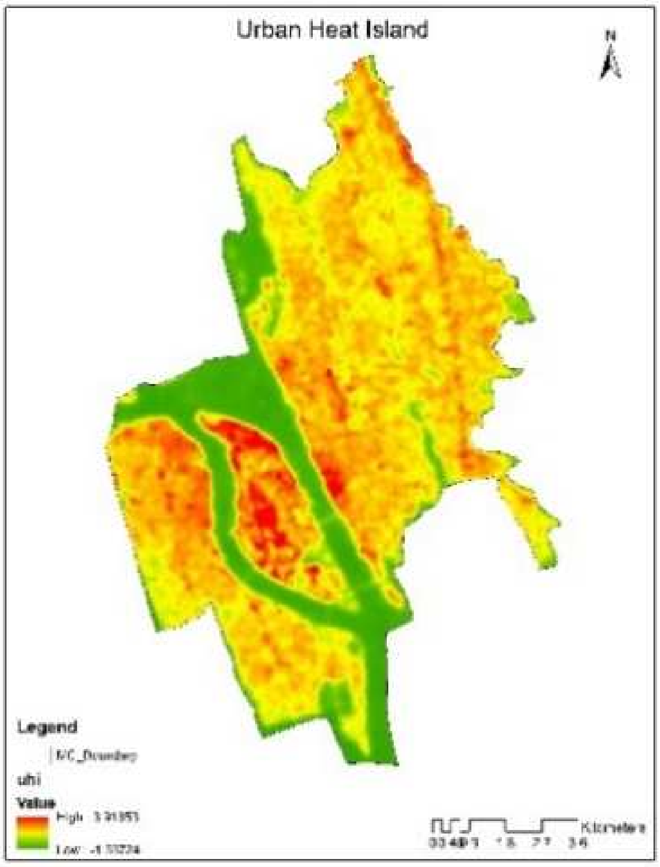


Figure 17:. Urban Heat Island. Source: authors.

7 OBSERVATIONS AND FINDINGS

The Urban Climatic Map and the severity of urban heat islands found in Kochi show the influence of built-up areas and other variables on the creation of heat islands and other climate-sensitive zones in the city limits. The city centre region, which has the highest concentration of anthropogenic activity, was where the intensity was at its peak. In areas of the region that were open and sparsely built, temperatures were lower. The differences between the low and high built-up regions were 4-5 °C due to the pockets of urban heat islands.

8 CONCLUSIONS

Shade trees, shrubs, vines, grasses, and ground cover cool the metropolis. Leaves and branches limit solar energy reaching the canopy. In summer, 10 to 30% of the sun's energy reaches the area under a tree, with the rest absorbed by leaves for photosynthesis and reflected into the sky. Forests and plants "transpire" water through their roots and leaves. Evapotranspiration cools air by evaporating water using air temperature. Evapotranspiration alone or with shade can lower peak summer air temperatures, according to research. The highest air temperatures in tree groves are 5 °C lower than on open land, irrigated agricultural fields are 3 °C lower than bare ground, and suburban areas with mature trees are 2 to 3 °C lower. Cooler than new suburbs without trees, while grass sports grounds are 1 to 2 °C cooler.

Another method is by using high albedo pavements. High-albedo pavement reflects more sunlight and absorbs less heat. High albedo pavement can reduce the urban heat island effect by reflecting more sunlight and absorbing less heat. High albedo pavement can be made using concrete, asphalt, and reflective coatings. White concrete and reflective coatings have albedo values of 0.7 or higher, compared to conventional pavements 0.05-0.15. Permeable pavements allow water to pass through rather than pool. These pavements reduce the urban heat by absorbing less heat. Permeable pavements are usually made of pervious concrete, permeable asphalt, or interlocking pavers with spaces between them. The soil filters and absorbs water that leaks through fissures. Permeable pavements reduce flood risk, stormwater runoff, and the urban heat island effect. Green roofing is another way to reduce urban heat. The vegetative covering on a roof is called a "green roof." Like trees and vegetation, green roofs shade surfaces and cool the air through evapotranspiration. These activities cool the roof and air. Green roofs can be installed on residences, offices, commercial real estate, government, educational, and industrial facilities. Heat islands, generated by multiple hot roofs in a city or suburb, can be reduced by cool roofing. Cool roofing solutions are made of highly reflective and emissive materials that can keep 28-33 °C cooler in peak summer weather. Cool roofs reduce energy usage, air pollution, greenhouse gas emissions, and human comfort but may cost more than standard roofing materials.

Finally the institutional mechanism shall begin with the local need for the mitigation efforts. Subsequently, an Inter-Agency coordination committee needs to be formed for reporting and planning the mitigation strategies for the heat islands. This involves thorough research and analysis of the current urban heat island situation, including an examination of local causes and effects. Countermeasures include reducing anthropogenic heat emissions, improving urban surfaces and structure, lifestyle adjustments, and public participation. Implementation includes improving monitoring, working with local governments, and raising awareness. However, this requires different criteria for analysis viz, change of human behaviour, political actions, economic means, etc., which reflects the practicalities and supplement with scientific knowledge for the use to the living conditions of the study region. Continuous research on causes in dynamic processes, and impacts and information interchange with other regions strengthen the effective implementation mechanism in the institutional governance system. Thus, operational framework stays successful by being reviewed and updated to reflect new research and technology to navigate toeards sustainable mitigation and improving Kochi's urban environment.

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